



RESEARCH DEPARTMENT



REPORT

**Acoustic scaling:
an evaluation of the proving experiment**

No. 1972/3

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ACOUSTIC SCALING: AN EVALUATION OF THE PROVING EXPERIMENT

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ACOUSTIC SCALING: AN EVALUATION OF THE PROVING EXPERIMENT

Summary

This report describes the conclusion of the first phase of the project on Acoustic Scaling in which a model of Studio 1, Maida Vale, has been constructed at one-eighth scale. Measurements involved in the selection of the materials to be used in the building and furnishing of the model are described, and an account is given of both the objective and subjective results obtained using the model. The results indicate that the modelling technique provides a useful tool for assessing the microphone sound quality that would be obtained from a full-size studio.

1. Introduction

This report is one of a series describing work on acoustic scaling in which a model is used to predict the acoustic quality of the sound that would be picked up by microphones in the full-size studio. In the general outline,¹ it was indicated that work has started on modelling Studio No. 1, Maida Vale, at one-eighth scale in order to prove the experimental technique of acoustic scaling.

A recording of non-reverberant music² is reproduced in the model at eight times normal speed by means of two special loudspeakers, and the sound is then picked up by miniature wide-range microphones and recorded at the high speed; the tape is then replayed at normal speed. The aim is that the sound quality obtained should be closely similar to that achieved by reproducing, at normal speed, the same recording of non-reverberant music in the full size studio, and picking up the sound using normal microphones. A subjective assessment of the studio quality, which cannot yet be measured objectively, can thus be made, and any action considered necessary in order to remedy acoustic impairments due to the studio can then be tested by means of experiments in the model.

This report describes the validation of the modelling technique, using the example of Maida Vale 1. Essential details of the equipment used are given elsewhere.³

2. Selection of acoustic materials for the model

Before deciding upon the materials from which the model should be made, it was necessary to determine the acoustical absorption coefficients of the existing surfaces and furniture in the real Studio 1, Maida Vale.

For many of the items, e.g. the designed acoustic treatment, plaster on brickwork, woodblock floors, etc.,

reference was made to previously measured BBC data on absorption coefficients.⁴ For some items, however, this was not possible, an important example being the ceiling of the studio, which is of an unusual and complex construction. Its acoustical absorption characteristics, in particular the low-frequency peak arising from vibration of the roof structure, were estimated and the estimate was found to be consistent with reverberation-time measurements in the studio.

Having assigned absorption coefficients to the various items in the real studio, it was then necessary to select materials that would adequately reproduce these characteristics in the scaled frequency-range used in the model. The assessment of suitability was made bearing four considerations in mind:—

- a) How accurately must the absorption coefficients of the model item match those of the real item?
- b) How consistent acoustically are samples of the proposed materials likely to be?
- c) Are the acoustical properties of the proposed material likely to alter after prolonged drying, or the passage of time?
- d) How many of the real features of the studio need be modelled?

2.1. Accuracy required

With regard to the characteristics of the absorbing surfaces in the model, it was hoped to obtain a reverberation time, for the model, within a tolerance corresponding to 0.1 s for the full-size studio. This was adopted as a target criterion and in retrospect, may even have been unnecessarily stringent. Brebeck⁵ cites the findings of three independent studies which indicate the differences in reverberation time varying from 8% to 20% are permissible before they are audible.

2.2. Consistency, between samples, of materials

Difficulties arising from inter-sample variability are not characteristic of model techniques alone. Full-scale acoustical design invariably entails the use of materials for which little or no quality control is exercised, during manufacture, with regard to acoustical properties. The only reasonable safeguard is to measure as many samples of the material as is practicable.

2.3. Changes in acoustical properties

As stated later in Section 3, it is necessary to maintain a very dry atmosphere in the model. However, no systematic study of the effects of prolonged drying, or of the passage of time, on the acoustical behaviour of materials is known to the authors. The acoustical absorption coefficients of the materials used in the model were measured after they had been dried sufficiently to enable a dry atmosphere to be maintained in the reverberation chamber, and there was no evidence to suggest that these values were unrepresentative of long-term values.

As the inside of the model would be considerably drier than the outside, the materials for the basic structure were chosen with some care in order to avoid problems of shrinkage or warping. 'Laminboard' of 'Gaboon through-out' was used to build the main structure of the model and, in practice, this has shown no tendency to warp or otherwise distort.

2.4. Degree of modelling required

For modelling to be an economically useful tool, the acoustical quality of a room must not be sensitive to minor changes in the shape or distortion of absorbents. For absolutely perfect modelling, these two characteristics should be reproduced accurately with errors considerably less than the wavelength of sound at the highest frequency of interest, i.e. about 30 mm in the real studio. This corresponds to dimensional errors of about 4 mm in the model, which present no insuperable difficulties, but experience shows that this degree of accuracy is not necessary in practice. No attempt was made to model the more minor paraphernalia of the studio such as microphone booms, music stands, etc., on the grounds that their positioning or even presence does not noticeably alter the acoustic quality of Maida Vale 1.

2.5. The materials selected

A general guide to the selection of some of the absorbents required is given by Brebeck,⁵ but it was necessary to check the absorption coefficients of all the materials used as the exact equivalence of items available in this country could not be taken for granted. The absorption coefficients were measured in a model reverberation room which has been described in an earlier report in this series.⁶ Table 1 gives the absorption coefficients of the modelling materials, at frequencies one-eighth of those used in the measurements, immediately following the appropriate data for the parts of the real studio which they simulated.

In general, absorbing materials of similar texture to those used in the real studio were employed, e.g. carpet was modelled by a particular type of velvet.

Some items (e.g. the carpet) are modelled quite accurately, but it was difficult to achieve the correct absorption characteristics at all frequencies for some of the others, this being particularly difficult at low frequencies. Fortunately, many of the inaccurately-modelled items are comparatively small in area and have a correspondingly small influence on the reverberation time. An attempt was made to balance out the inaccuracies so that the total absorption and hence the reverberation time would be correct.

2.5.1. Model orchestra players

The determination of the required absorption characteristics for the model orchestral players presented some difficulties. Until about 1960 it was the practice to ascribe an equivalent absorption to a single person; to obtain the absorption of a group, this figure was simply multiplied by the number of persons. This procedure has since been questioned by a number of workers. Beranek,⁷ for instance, presents strong evidence that under certain conditions the equivalent absorption of audiences in concert halls is proportional to the area occupied rather than the number of persons present.

In Maida Vale 1 each member of the orchestra occupies about 2.3 m² of floor area. This area per seat appears to be neither so large that the 'per person' absorption is appropriate nor so small that the 'per unit area' absorption is appropriate. It is well in excess of the 0.75 m² per person for audiences considered by Beranek, so his data could not be applied with any confidence to the model of Studio 1.

It was therefore necessary to carry out measurements on real, normally clothed, seated persons, spaced so as to allow 2.3 m² of floor area each. The resulting equivalent absorption per person, from reverberation room measurements, is shown in Fig. 1. Models were then developed which had similar scaled-up absorption characteristics when measured in a geometrically similar arrangement, i.e. in the one-eighth scale model reverberation room.

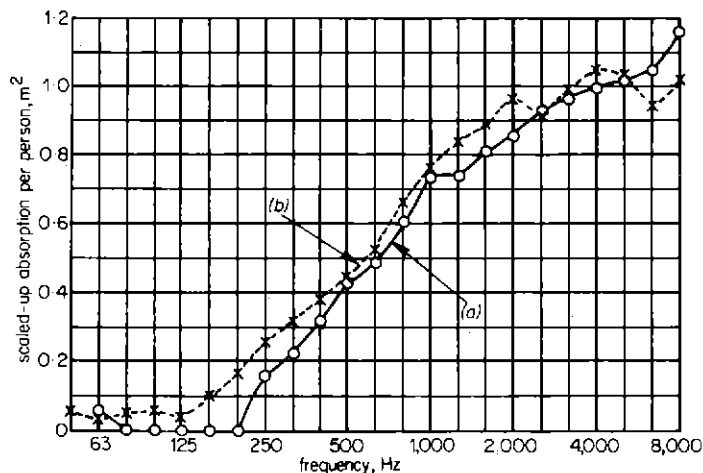


Fig. 1 - Absorption of orchestral personnel

(a) Absorption of real persons (b) Absorption of model musicians

TABLE 1

Absorption Coefficients of Materials used in the Real Studio and of Model Materials

Type of Surface	Absorption Coefficients at the Specified Frequencies						
	63	125	250	500	1000	2000	4000 Hz
Plaster on brick	0.01	0.02	0.02	0.03	0.03	0.04	0.05
Laminboard, polyurethane varnished	0.06	0.04	0.01	0.00	0.00	0.00	0.00
Plaster ceiling over audience	0.10	0.10	0.05	0.03	0.03	0.03	0.02
Varnished plywood	0.05	0.05	0.10	0.10	0.10	0.10	0.10
Main ceiling	0.15	0.22	0.15	0.07	0.03	0.03	0.02
Vinyl wallcovering over 32 mm lightly damped airspace	0.13	0.18	0.12	0.02	0.00	0.00	0.00
Wood block floor	0.05	0.04	0.04	0.06	0.07	0.08	0.08
Plastic-faced 3 mm hardboard	0.06	0.05	0.09	0.15	0.10	0.07	0.03
Carpet with underfelt	0.02	0.04	0.13	0.36	0.60	0.69	0.62
Velvet, 0.46 kg/m ²	0.04	0.08	0.19	0.45	0.67	0.69	0.67
Audience seating area	0.27	0.45	0.60	0.73	0.80	0.75	0.64
Modelled seats and velvet	0.20	0.28	0.40	0.72	0.76	0.75	0.70
Roofing felt over 80 mm damped airspace	0.23	1.05	0.45	0.19	0.15	0.15	0.15
Vinyl wallcovering over 15 mm damped airspace	0.10	0.50	0.68	0.20	0.09	0.00	0.00
Roofing felt over 200 mm damped airspace	0.43	0.91	0.55	0.30	0.15	0.00	0.00
Vinyl wallcovering over 25 mm damped airspace	0.60	0.72	0.27	0.12	0.03	0.00	0.00
Roofing felt over 300 – 500 mm damped airspace	0.80	0.60	0.40	0.25	0.15	0.00	0.00
Vinyl wallcovering over 35 mm damped airspace	0.50	0.68	0.20	0.09	0.00	0.00	0.00
Cupboards	0.30	0.30	0.20	0.10	0.06	0.06	0.08
Varnished plywood	0.13	0.18	0.12	0.02	0.00	0.00	0.00
Wainscot: 6 mm plywood over rockwool	0.50	0.60	0.30	0.12	0.06	0.06	0.08
Vinyl wallcovering over 13 mm damped space	0.31	0.46	0.33	0.13	0.08	0.06	0.07
Absorbers on rear wall: Rockwool with perforated facing	0.15	0.50	0.70	0.60	0.40	0.20	0.10
Perforated p.v.c. over felt	0.50	0.70	0.50	0.60	0.40	0.20	0.10
Chorus seating	0.30	0.30	0.20	0.10	0.06	0.06	0.08
Model seating	0.09	0.10	0.11	0.11	0.09	0.13	0.09
5% perforated hardboard over 25 mm rockwool over 50 mm airspace	0.00	0.03	0.37	1.00	0.90	0.50	0.30
5% perforated p.v.c. over 3 mm felt over 6 mm airspace	0.30	0.50	0.90	1.00	0.65	0.30	0.20
Curved diffusers (A) (6 mm plywood on frames) 1½ mm varnished plywood	0.30	0.40	0.20	0.12	0.06	0.06	0.08
	0.05	0.05	0.10	0.10	0.10	0.10	0.10
Curved diffusers (B) (13 mm fibreboard on frames) 1½ mm varnished plywood	0.15	0.25	0.35	0.20	0.20	0.20	0.20
	0.05	0.05	0.10	0.10	0.10	0.10	0.10
Orchestral rostra	0.51	0.43	0.18	0.10	0.10	0.10	0.10
Modelled rostra, 6 mm ply	0.25	0.11	0.07	0.04	0.00	0.00	0.00



Fig. 2 - Appearance of model musician

The final models of musicians are shown in Fig. 2; their shape corresponds roughly to a seated person so they should diffract sound waves in a similar way. They are similar to the one-tenth scale models described by Day⁸ but

are of simpler construction, being cut from expanded polystyrene, with pieces of 5 mm thick felt stuck on the back. The absorption characteristic, per person (Fig. 1) corresponds well with that obtained using people.

3. Optimal humidity

In a studio as large as Maida Vale 1, the sound absorption due to the air in the room is, at high frequencies, a substantial proportion of the total absorption. For accurate scaling, the attenuation per unit 'scaled-down' wavelength in the model should be the same as that obtained, per normal wavelength, in the real studio, i.e. in the model, the attenuation per metre at a frequency $8f$ should be eight times the attenuation per metre existing at a frequency f in the real studio.

This condition would be automatically satisfied if the attenuation per metre were proportional to frequency. However, as discussed in an earlier report,⁶ the attenuation in air is composed of a part which increases as the square of the frequency (classical absorption) and an additional part (molecular absorption) which varies with both the humidity and frequency.

Fortunately, it is possible, in practice, to compensate for the excessive classical absorption in the model by drying the air to a suitable degree. Fig. 3 shows how close the matching can be for a one-eighth scale model, and it indicates that 1.5% relative humidity (R.H.) in the model is required to match the prevailing 50% R.H. in the real studio. The graph also shows that if the humidity of the model

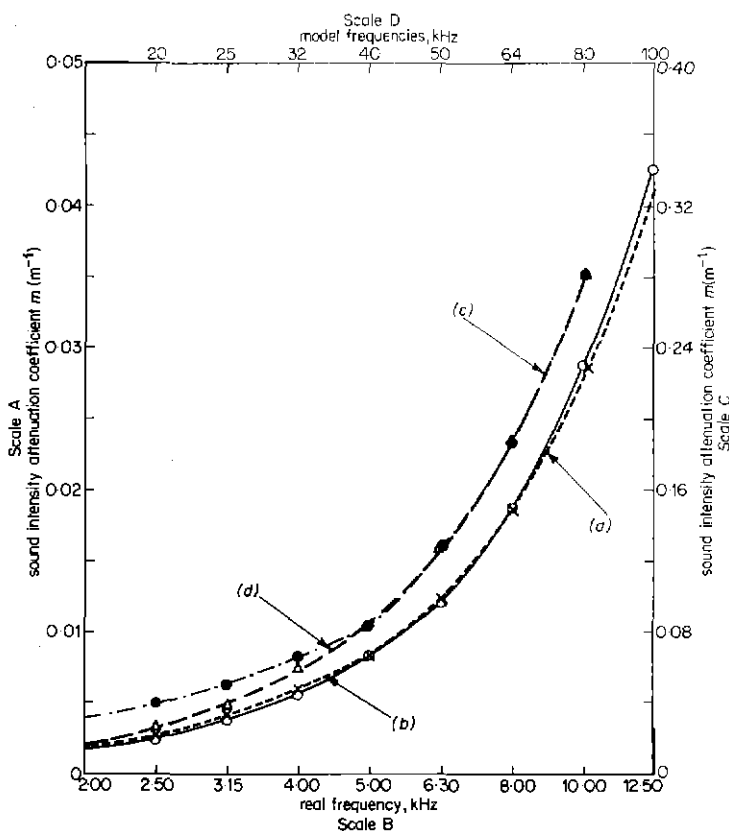


Fig. 3 - Optimum humidity for model:— comparison of calculated attenuation of air in Maida Vale Studio 1 with scaled attenuation of air in the model for two values of relative humidity

- (a) Model 1.5% R.H. (b) Studio M.V.1 50% R.H.
(c) Model 5% R.H. (d) Studio M.V.1 40% R.H.

risks to 5% R.H. a reasonable approximation to 40% R.H. in the studio is attained. For Fig. 3, data on the absorption of air in the range 10 – 100 kHz was obtained from Pohlmann,⁹ for the range 2 kHz to 10 kHz the data of Harris¹⁰ was used. Harris's figures, which are probably the most reliable to date, indicate values of optimal humidity somewhat lower than those given by earlier authorities.

4. Reverberation time of the model studio

Figure 4 shows the reverberation-time/frequency characteristic of the unoccupied real studio together with the corresponding scaled-up characteristics of the unoccupied model, for two different values of relative humidity. Although the differences in reverberation time between the studio and the model containing air at 4% R.H. are, at some frequencies, larger than was hoped, they are reasonable taking into account the probable errors in the absorption coefficients for both the model and the modelled items.

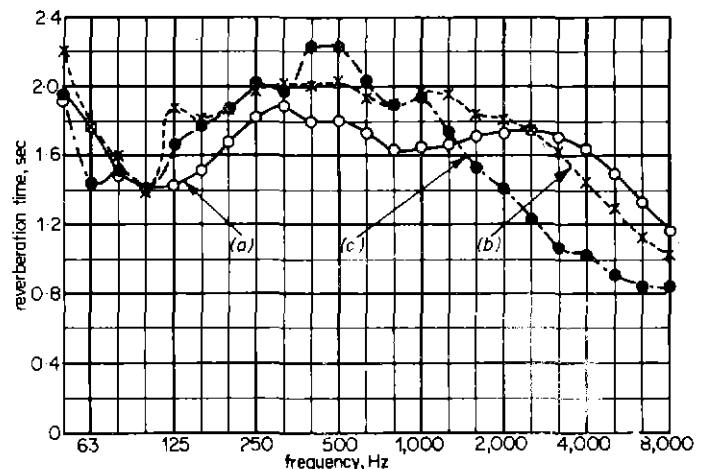


Fig. 4 - Reverberation time. Comparison of reverberation time of empty Maida Vale Studio 1 with scaled up reverberation time for the empty model
(a) Studio M.V.1 (b) Model 4% R.H. (c) Model 28% R.H.

In the event, music reproduced through the model system sounded so similar to that reproduced through the studio that no attempt was made to match the reverberation-time/frequency characteristic more closely.

It is worth noting the deterioration in reverberation-time/frequency characteristic as the relative humidity in the model is raised to 28% (Fig. 4), confirming that the precautions taken in drying the model were necessary and sufficient.

Figure 5(a) shows the reverberation-time/frequency characteristic when 70 model musicians were placed in the model. The reduction in reverberation time is consistent with that predicted from calculations using the data of Fig. 1.

Figure 5 also gives the results of reverberation-time measurements made in the real studio with an orchestra of 60 present (curve b) and a choir of 70 present (curve c). The measurements were made by analysing recordings of pistol shots (in the case of the orchestra) and of musical

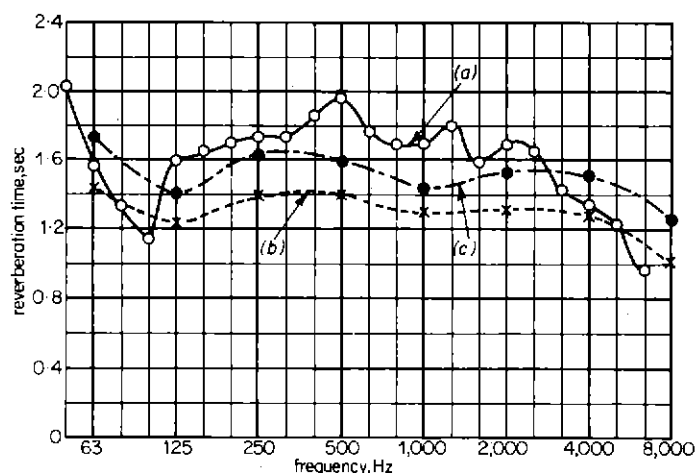


Fig. 5 - Reverberation time. Comparison of reverberation time of Maida Vale Studio 1 with scaled up reverberation time for model

- (a) Model with 70 model musicians
- (b) Studio M.V. 1 with orchestra of 60 present
- (c) Studio M.V. 1 with 70 choir members present

chords (in the case of the choir). The low reverberation times with the orchestra present are surprising and unexplained, even when due allowance is made for the less accurate measurement technique. The measurements of the empty studio were made at 20 microphone positions, using short bursts of one-third octave-band noise, and the results processed by computer. With the orchestra present, the pistol was fired at five positions and recordings made at two microphone positions for each shot; analysis was carried out by the visual examination of paper records showing the decay rates for octave bands.

Although the addition of the model musicians did not produce a very great reduction in the reverberation time itself, the effect on music processed through the model was subjectively obvious and the change appeared to be in quality rather than in reverberance.

This and other effects due to changes in the model will be discussed in the next section.

5. Tonal quality

It was mentioned in the Introduction that tonal quality would be tested using a stereo recording of non-reverberant music reproduced over two monitoring loudspeakers in Studio 1, Maida Vale, compared with a similar reproduction after processing in the model. Although this arrangement in the studio may seem to be arbitrary and does not closely simulate an orchestra it does give the possibility of being closely copied in the model and is thus highly appropriate for a proving experiment.

In the first instance the real studio was used empty and the tape was replayed through a pair of monitoring loudspeakers type LS 5/5 and later through a pair of loudspeakers type LSU/10. The test was repeated in this way in order to allow some estimation to be made of the effect on the overall quality of differing monitoring loudspeakers.

The sound was picked up by omnidirectional microphones spaced 5 m (16 ft) apart and 10 dB of 'cross-mix' was employed; spatial effects in the studio could thus be appreciated. Omnidirectional microphones were employed as only this type was available for use in the model.

For the tests in the model the loudspeakers had been pre-equalised in accordance with their measured free-field axial response/frequency characteristics. It is known from previous experience that this is insufficient to produce first-class quality and therefore, in addition, a listening test was devised. A test tape was reproduced, at high speed, through the loudspeakers when mounted in a free field room on a base corresponding to the floor and rostrum of the model; the output was then recorded through an equalised microphone and transposed down to normal frequencies. The transposed signal was then reproduced on a high-grade monitoring loudspeaker and the original equalisation was modified to yield the best overall sound quality. Under these conditions the comparison between the sound quality from the model with that from the studio showed that a very large measure of similarity had been obtained. Observers who knew the studio well complained, however, that in neither case was the tonal quality representative of the studio in normal use, i.e. with a large orchestra. The complaint was not that the reverberation characteristics sounded wrong but that the tonal quality itself, particularly of the strings, was different.

Further recordings were therefore made in the studio, with about seventy members of the choir sitting in the places normally occupied by the orchestra. The same technique was used as before and it was clear that there was indeed a tonal change in the sound quality compared with that obtained with the studio empty, a change which could neither be predicted from the absorption characteristics of the orchestra nor measured objectively.

In order to duplicate this condition the recordings in the model were repeated using model musicians with the appropriate absorption characteristics (see Section 2.5.1).

On replay it was immediately evident that, as with the real studio, the tonal quality had changed, becoming appreciably harder; in particular the string tone had become 'wiry'. Similarity between the sound quality from the studio and that from the model was regarded, by a group of persons accustomed to making critical acoustic judgements, as sufficiently close that the modelling techniques could be regarded as proved.

6. Conclusions

The accuracy of the objective tests of the modelling technique (reverberation time) is regarded as satisfactory. More important, the success of the model in showing up the change in tonal quality produced by the presence of an orchestra illustrates the value of the modelling techniques, as no known objective tests would have predicted or measured this effect; the view that the sound quality in the studio is satisfactory for solo instruments and small chamber orchestras, but not for large symphony orchestras and choirs, is borne out by the results obtained using the model.

In view of the success of the proving experiment it is now envisaged that a detailed statistical examination of opinions as to the nature of the complaints about the sound quality obtained from the studio with a large orchestra will be carried out, and attempts will be made to use the model to investigate their causes.

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